

face is exposed to silicic acid/KOH roughening solution and  $\text{SiCl}_4$  plasma treatment and HCl cleaning. The third curve (3) shows the result when the contacts of curve (2) are annealed at  $340^\circ\text{C}$ . for 5 seconds. The linear IV curve (3) is characteristic of an ohmic contact.

In an example, the present method includes the following sequence of steps:

(1) Lap and polish a nitrogen face of c-plane, n-type GaN with a carrier concentration of  $1 \times 10^{18}/\text{cm}^3$ .

(2) Prepare a silicic acid-potassium hydroxide solution, with the composition of 14.6 g of silicic acid hydrate, 20 mL of 45% KOH solution, and 100 mL of water.

(3) Immerse the polished surface of the n-type GaN substrate in silicic acid—potassium hydroxide solution for 15 min at  $60^\circ\text{C}$ .

(4) Perform standard n-contact liftoff lithography:

Lithography is not required except to form the contact pattern. This step may be skipped and a blanket deposition/etchback used.

(5) Descum (optional), for example, using ozone cleaning, or ozone plasma.

(6) Expose the sample to  $\text{SiCl}_4$  plasma, for example, Reactive ion etching at 400 W and 30 mTorr  $\text{SiCl}_4$ .

(7) Deionized water rinse.

(8) Immerse the sample in HCl (37%) for 5 min.

(9) Deionized water rinse.

(10) Deposit contact metallization, such as evaporated aluminum, aluminum/nickel/gold, and/or titanium/gold.

(11) Anneal. Depending on the treatment conditions, contacts are ohmic as deposited, or require mild annealing between  $200^\circ\text{C}$ . and  $450^\circ\text{C}$ . to be ohmic.

This sequence of steps is merely illustrative, and should not limit the scope of the claims herein. Depending upon the embodiment, the steps may be further combined, or other steps may be added. Alternatively, the steps may be reordered, depending upon the embodiment.

GaN substrates that underwent plasma exposure only, or acid clean only, had high-resistance contacts. Plasma exposures included both  $\text{SiCl}_4$  plasma and chlorine-based plasmas. Acid cleaning included HCl, buffered oxide etch, and/or HF. GaN substrates that did not receive plasma exposure sometimes had ohmic contacts as deposited, but became high-resistance contacts on mild annealing ( $340^\circ\text{C}$ ., 5 second). Substrates exposed to alkaline cleaning, plus plasma treatment and acid dip, had generally high contact resistance as-deposited, but the contact resistance dropped below the current laser-scribed value after a  $340^\circ\text{C}$ ., 5 second anneal.

It should be understood that the description recited above is an example of the invention and that modifications and changes to the examples may be undertaken which are within the scope of the claimed invention. Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements, including a full scope of equivalents.

What is claimed is:

1. A method for fabricating LED devices, the method comprising:

providing a gallium and nitrogen containing substrate member comprising a backside surface and a front side surface, the front side surface including an n-type material overlying the substrate member, an active region overlying the n-type material, and a p-type material overlying the active region;

subjecting the backside surface to a polishing process, causing a backside surface characterized by a surface roughness;

subjecting the backside surface characterized by a surface roughness to an anisotropic etching process exposing various crystal planes to form a plurality of pyramid-like structures distributed spatially in a non-periodic manner on the backside surface, wherein the anisotropic etching process comprises use of a solution comprising silicic acid and potassium hydroxide;

treating the backside surface comprising the plurality of pyramid-like structures, to a plasma species to form a plasma-treated backside surface;

subjecting the plasma-treated backside surface to a surface treatment to form a surface-treated backside; and

forming a contact material comprising an aluminum bearing species or a titanium bearing species overlying the surface-treated backside to form a plurality of LED devices with the contact material.

2. The method of claim 1, wherein the backside surface is characterized by a nitrogen face of a c-plane, and n-type GaN characterized by a carrier concentration ranging from  $1 \times 10^{15}/\text{cm}^3$  to  $1 \times 10^{20}/\text{cm}^3$ ; wherein the surface roughness ranges from about 0.3 nm to 200 nm.

3. The method of claim 1, wherein the polishing process comprises use of a diamond slurry mixture characterized by a particle size ranging from 0.05 microns to 5 microns.

4. The method of claim 1, wherein each of the plurality of pyramidal-like structures is characterized by a height from about 20 nm to about 1,000 nm.

5. The method of claim 1, wherein the solution comprises 0% to 20% by weight silicic acid hydrate, and 3% to 45% by weight potassium hydroxide in water.

6. The method of claim 5, wherein the backside surface is immersed in the solution for at least 1 minute at a temperature from  $0^\circ\text{C}$ . to  $100^\circ\text{C}$ .

7. The method of claim 1, wherein the plasma species comprises a silicon species and a chlorine species derived from a silicon tetrachloride gas source.

8. The method of claim 1, wherein the surface treatment comprises an HCl immersion for at least one minute.

9. The method of claim 1, further comprising subjecting the LED devices to a thermal treatment process to form an ohmic contact between each LED device and the contact material.

10. A method for fabricating LED devices, the method comprising:

providing a gallium and nitrogen containing substrate member comprising a backside surface and a front side surface, the front side surface including an n-type material overlying the substrate member, an active region overlying the n-type material, and a p-type material overlying the active region;

subjecting the backside surface to a polishing process, causing a backside surface characterized by a surface roughness;

subjecting the backside surface characterized by a surface roughness to an anisotropic etching process exposing various crystal planes to form a plurality of pyramid-like structures distributed spatially in a non-periodic manner on the backside surface, the plurality of pyramid-like structures characterizing a roughened region overlying a plane within a vicinity of the backside region, wherein the anisotropic etching process comprises use of a solution comprising silicic acid and potassium hydroxide;

treating the backside surface, comprising a plurality of pyramid-like structures, to a plasma species to form a plasma-treated backside surface;

subjecting the plasma-treated backside surface to a surface treatment to form a surface-treated backside; and